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PAPER ON

MEASURING THE SUSTAINABILITY OF AGRICULTURAL SYSTEMS AT THE FARM LEVEL

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MEASURING THE SUSTAINABILITY OF AGRICULTURAL SYSTEMS AT THE FARM LEVEL[1]

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ABSTRACT

An agricultural system is said to be sustainable at the farm level if it satisfies the farmer's needs and at the same time conserves the natural resource. Commonly used indicators of farmers' satisfaction are productivity, profitability, stability and viability; while that for resource conservation are quality and quantity of soil, water and nutrient. Measurable surrogates of these indicators are yield, profit and frequency of crop failure for farmer satisfaction, soil depth, organic matter content, and permanent ground cover for resource conservation.

An indicator is said to be at a sustainable level if it exceeds a designated threshold level as given below:

INDICATOR	THRESHOLD LEVEL
Yield	20% more than average yield in the community
Profit	20% better than average of the community
Frequency of crop failure	20% or average of community if higher than 20%
Soil depth	Average of similar soil types in community
Organic Matter	1% or average of community if higher than 1%
Permanent ground cover	15% or average of community if higher than 15%

On the basis of the above indicators and threshold levels, an agricultural system is said to be sustainable if the average of indicators (expressed as units of their respective threshold levels) for farmer satisfaction and for resource conservation are both positive. For sustainable systems, their level of sustainability can be quantified in two ways: (1) as the combined average of the ratings for farmer satisfaction and resource conservation, and (2) as an area bounded by the radar polygon for farmer satisfaction and resource conservation.

This procedure for evaluating sustainability was applied to actual data from farms in Guba, Cebu and our experience shows that the procedure can be implemented easily and the results are consistent with our expectations.

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A. INTRODUCTION

Sustainable agriculture has been equated to almost all that is good for the farmer, his farm, and the wider environment. Profitability, stability, productivity, acceptability and environmental friendliness are some of the qualities now associated with sustainable agriculture. Considering that each of these qualities is complex and can be defined in several ways, it is no surprise that the definition and measurement of sustainable agriculture has been very elusive.

There are two potential approaches for defining and measuring sustainable agriculture. One is based on the principle that the important indicator of sustainability are location specific and change with the situation prevailing on a farm. For example, in the steeplands, soil erosion is an important component of sustainability, but in the flat lowland rice paddies, soil loss due to erosion is insignificant and may not be a useful indicator. Based on this principle, therefore, the protocol for measuring sustainability starts with a list of potential indicators from which practitioners selects a subset of indicators which is felt to be appropriate for the particular farm being evaluated.

The other approach is based on the principle that the definition and consequently the procedure for measuring sustainable agriculture is the same regardless of the diversity of situations that prevails on different farms. Under this principle, sustainability is defined by a set of requirements that must be met by any farm regardless of the wide differences in the prevailing situation. For example, in the steepland and in the lowland rice paddies, described above, soil erosion is an important indicator of sustainability, accepting that this requirement is more easily met in the latter situation.

There are clear advantages and disadvantages between these two approaches to assessing sustainability. The principle of location specificity avoids the difficulty of selecting and agreeing on a common set of indicators, a task that is always controversial. In addition it allows each practitioner the freedom to choose their own indicators, a feature that is very attractive among workers at the grassroots level. A major drawback with the location specific approach is the difficulty of comparing results from farms where different indicators have been selected. Here lies the strength of the second approach of constant indicators across all farms. All measurements are based on the same indicators and the results are comparable across farm and are easier to analyze for repeatability and replicability.

This paper assumes that the second principle of a common definition and set of indicators for measuring sustainability is a much more powerful and useful concept for studying sustainable agriculture. It proposes a protocol for measuring sustainability at the farm level by:

1) defining the requirements for sustainability,
2) selecting the common set of indicators,
3) specifying the threshold levels,
4) transforming the indicators into a sustainability index, and
5) testing the procedure using a set of data from selected farms in the Philippines.

B. DEFINITION AND REQUIREMENTS FOR SUSTAINABILITY

At the farm level, a farming system is considered sustainable if it conserves the natural resource and continues to satisfy the needs of the farmer, the manager of the system. Any system that fails to satisfy these two requirements are bound to change significantly over the short term and is therefore considered not sustainable.

Farmer satisfaction and resource conservation, the two requirements of sustainability, are not simple characters but are influenced by a host of factors. High yield, low labor requirement, low input cost, high profit, and stability are some of the features that are likely to enhance farmer satisfaction. Natural resource conservation, however, is usually associated with soil depth, water holding capacity, nutrient balance, organic matter content, ground cover and biological diversity.

This definition has many similarities with the Framework for Evaluating Sustainable Land Management (FESLM), proposed by FAO. The first three pillars of FESLM, productivity, stability and viability are the main components of farmer satisfaction; while the fourth, protection and conservation are the components of resource conservation. The fifth and last pillar, social acceptability is a community level parameter and is not included at the farm level.

C. THE INDICATORS OF SUSTAINABILITY

Even with the simplified requirement for sustainability at the farm level, the number of indicators that are commonly mentioned are many. Shown in **Appendix 1** is a list of some of these indicators and the procedure for measuring them. It is clear that several indicators are closely related to each other and it is not necessary to measure all of them. Those that should be selected must posses one or more of the following features:

1) be easy to measure,
2) respond easily to change,
3) have obvious boundaries (threshold) separating sustainable from unsustainable conditions, and
4) be directly related to the two requirements for sustainability.

Using the above guidelines, the following indicators were initially selected: yield, profit and variance of profit as indicators of farmer satisfaction and soil loss, nutrient balance and organic matter as indicators of resource conservation. However, variance of profit, soil loss, and nutrient balance were considered too difficult to measure directly and the following surrogate indicators were used instead: frequency of crop failure, soil depth and percent permanent ground cover.

Of the six indicators selected, only the last one, permanent ground cover posses a problem in terms of universality. For example, in steepland where soil conservation practices are needed, permanent ground cover serves as a useful indicator. However, in the flatlands where soil conservation may be of little importance, ground cover may not be so relevant.

D. THE THRESHOLD LEVEL

The term threshold level is used to denote the boundary between sustainable and unsustainable values. Unless this threshold level is specified for each indicator, it is not possible to distinguish between sustainable and unsustainable conditions.

In this paper, the primary basis for the threshold level is the average of the community instead of an absolute value for all situations. This seems reasonable since farmers usually judge their state of well being on the basis of their position relative to their neighbors, and since farms that apply good conservation practices are expected to retain their initial resource endowment. With this procedure it is expected that the threshold levels for communities with widely different economic and biophysical environment will also differ widely. Shown in **Table 1** are the threshold levels for the indicators used in measuring sustainability.

Table 1: Threshold for sustainability indicators.

Indicator	Threshold Level	Formulae
Yield (X_1)	20% more than average yield in the community	1.2 $\bar{x}_1$
Profit (X_2)	20% better than average of the community	1.2 $\bar{x}_2$
Frequency of crop failure (X_3)	20%, or average frequency for the community whichever is lower	0.20 when $\bar{x}_3 \geq 0.20$, $\bar{x}_3$ otherwise.
Soil depth (X_4)	Average of similar soil types in the community	$\bar{x}_3$
Organic Matter (X_5)	1%, or average of community, whichever is higher	0.01 when $\bar{x}_5 \leq 0.01$, $\bar{x}_5$ otherwise
Permanent ground cover (X_6)	15%, or average of community, whichever is higher	0.15 when $\bar{x}_6 \leq 0.15$, $\bar{x}_6$ otherwise

E. THE COMPUTATIONAL PROCEDURE

To illustrate the procedure for computing the sustainability index at the farm level, we use data from ten farms in Guba, Cebu, Philippines (**Table 2**). Guba is a farming community of about 1000 households cultivating the slopes of the mountains surrounding Cebu City. About fifteen years ago, the World Neighbors, a church based organization, decided to introduce contour hedgerow farming into Guba in an effort to conserve the soil and related resources. Today about 60 percent of the community has adopted the new technology. Of the 10 farms given in **Table 2**, the first six are adaptors of the contour hedgerow technology while the remaining four are not. For data given in the table, yield, profit and frequency of crop failure are survey data while soil depth, organic carbon and permanent cover are measurement data.

Table 2: Sustainability Indicators for 10 farms in Guba, Cebu.

Farm No.	Farmer Satisfaction			Resource Conservation		
	Yield (kg/ha)	Net Income ($/ha)	Freq. of Crop Failure (%)	Soil Depth (cm)	OM (%)	Perm. Ground Cover (%)
1	1.88	252	15	117	1.15	25
2	1.42	163	20	80	0.52	14
3	1.43	195	20	87	.72	17
4	2.02	247	30	37	.60	14
5	1.75	203	25	86	1.26	16
6	1.62	227	25	70	0.80	14
7	.88	38	20	47	1.61	7
8	.52	30	15	27	0.82	0
9	.98	116	20	100	1.74	0
10	.81	29	15	42	0.82	1
Average	1.33	150	20.5	69.3	1.06	10.8
Threshold	1.60	180	20.0	69.3	1.06	15.0

The computation of the index of sustainability for each of the ten farms is as follows:

Step 1: Specify the threshold level for each indicator following the formula given in **Table 1**. Convert all measurements into threshold units as shown in **Table 3.**

Step 2: Represent the relative sustainability of farms graphically for visual comparison (Figure 1). Note that the specific components that results to non-sustainability are easily seen from these graphs.

Step 3: Compute the indices for farmer's satisfaction and resource conservation as the average of their three respective indicators. These two averages must both be equal to or greater than one for the system to be judged sustainable. For our example, only farms No. 1 and No. 5 are judged sustainable.

Step 4: For sustainable cases, compute the average of the two indices. This average is the final index of sustainability which is equal to 1.48 for farm No. 1 and 1.08 for farm No. 5. Note that the sustainability index is computed for sustainable systems

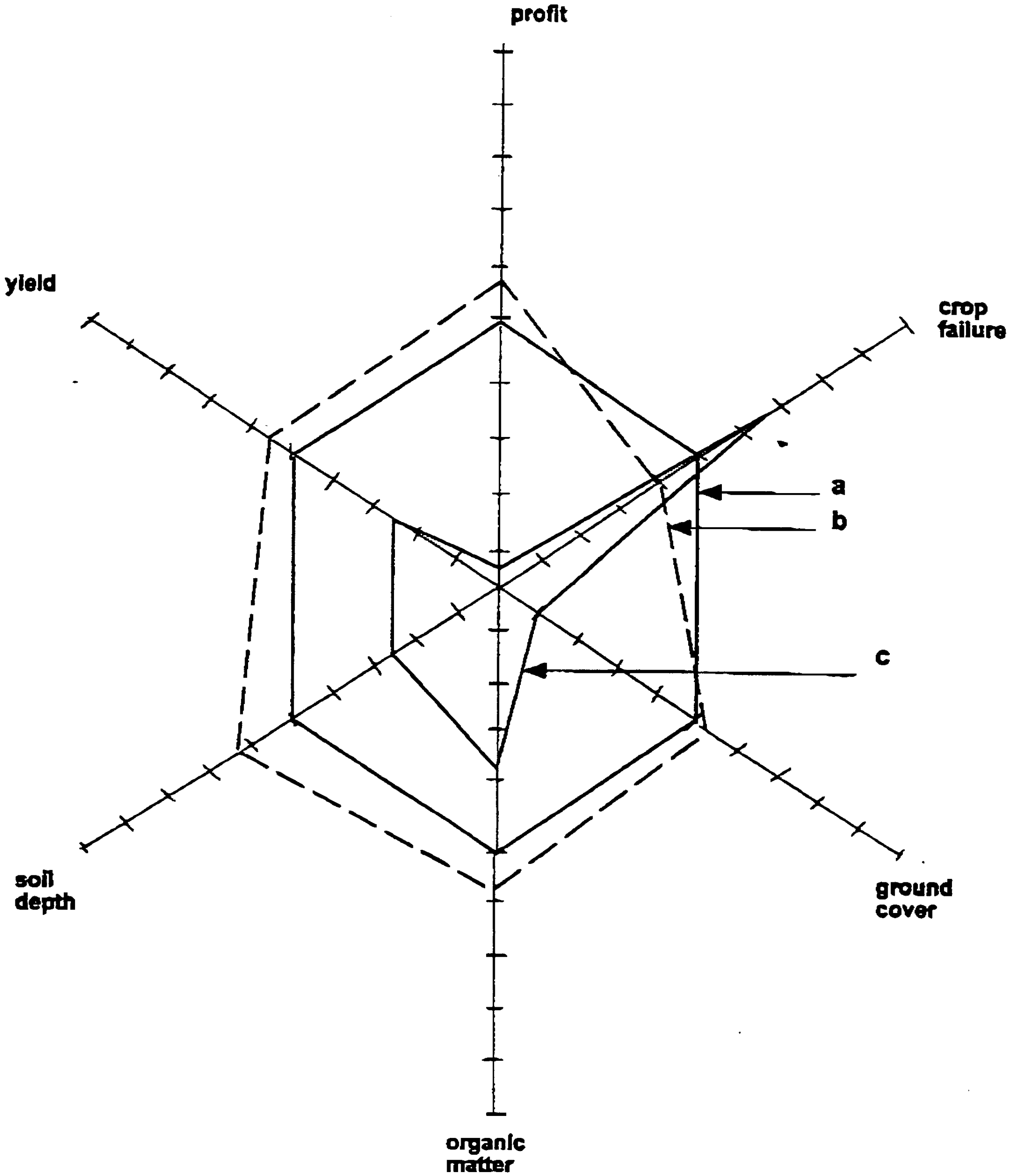

Figure 1: Radar graph showing: (a) the threshold line, (b) the sustainability of farm no. 5 with a bounded area exceeding that of the threshold even as one indicator is below threshold, and (c) the unsustainable situation in farm No. 10 with five out of six indicators below threshold. (Bruce & Kelly 1995)

Measuring the Sustainability of Agricultural Systems at the Farm Level
Measuring the Sustainability of Agricultural Systems at the Farm Level

only, i.e., no index is computed for farm that are judged non-sustainable. Thus, the sustainability index is always positive and greater than 1.0, the higher the value, the more sustainable.

Table 3: Sustainability indices for 10 farms in Guba, Cebu.

Farm No.	Satisfaction Farmer				Resource Conservation				Sustainability Index
	Yield	Profit	Crop Failure	Index	Depth	OM	Ground Cover	Index	
1	1.18	1.40	1.33	1.30	1.69	1.65	1.66	1.66	1.48
2	0.89	0.90	1.00	0.93	1.15	0.49	0.93	0.85	NS
3	0.89	1.08	1.00	0.99	1.25	0.68	1.13	1.02	NS
4	1.26	1.37	0.66	1.10	0.54	0.57	0.93	0.68	NS
5	1.09	1.13	0.80	1.01	1.24	1.18	1.07	1.16	1.08
6	1.01	1.26	0.80	1.02	1.01	0.75	0.93	0.89	NS
7	0.55	0.21	1.00	0.59	0.68	1.51	0.47	0.88	NS
8	0.32	0.16	1.33	0.60	0.39	0.77	0.00	0.38	NS
9	0.61	0.64	1.00	0.75	1.44	1.64	0.00	1.02	NS
10	0.51	0.16	1.33	0.67	0.61	0.77	0.07	0.48	NS

F. SOME NOTES ON INDEX

As a consequence of the procedure with which the index is computed, several characteristic features that are worth noting. These features are discussed below:

A. *The requirements for sustainability.* An average rating of more than of 1.0 for farmer's satisfaction and resource conservation is necessary for the system to be sustainable. This requirement can be met even if some indicators are below the threshold level (i.e., less than 1.0). For example, average rating for farmer's satisfaction or resource conservation may exceed 1.0 even if one or more indicator has a rating of less than 1.0. This means that a deficiency in one indicator can be compensated for by excess capacity in another. For example, in farm no. 5, frequency of crop failure is below threshold but yield and income are high enough to compensate for the deficiency. Note, however, that this ability to compensate is allowable only among indicators of the same index, (i.e., within farmer satisfaction) but not across. Thus excess rating in yield or income can not compensate for deficiencies in soil depth and organic matter.

B. *Sustainability at the community level.* Changes in the threshold level, over time, is a key indicator of sustainability at the community level. Note that communities that upgrades their management practices should consistently improve their level of productivity and natural resource endowment which then should be reflected in ever improving threshold levels. Thus, improving threshold level, over time, is indicative of sustainability at the community level; and conversely, a decreasing trend indicates non-sustainability.

C. *The radar graph.* This graph is a good tool to immediately visualize and identify the specific component practice that result to non-sustainability. It helps us understand the differences across farms or over time in the same farm. Hence, overall sustainability is not just reduced to a single analogue derived from a common perspective but becomes a useful tool to planning for further action.

D. *Level of sustainability.* It should be noted that once the sustainability requirement is satisfied, a general index is computed whose value is indicative of the number of times that the threshold level is surpassed. For example, an index of one indicates that the system is at threshold level, an index of two means that the system is two times the threshold, and so on.

E. *Flexibility to accommodate additional indicators.* In terms of procedure it should be obvious that there is no difficulty in accommodating additional indicators under each of the two main pillars. Since the indices are averaged across indicators adding more indicators should not unduly complicate the process nor the level of comparability among indices.

G. CONCLUSION

The procedure outlined in this paper has been developed from a definition of sustainability at the farm level which provides two sets of indicators relative to farmer satisfaction and resource conservation. It has been selected for its ease in implementation both in data gathering and in data analysis. Experience in applying this procedure to farms in Guba strongly collaborate this desired simplicity. The data are easy to gather and the analysis is simple. We plan to repeat the process in another community where measurement data will be used for all indicators.

The net effect of grouping indicators into two requirements for sustainability is to reduce the strictness with which farms can be judged as sustainable. The fact that there is a given level from substitutability among indicators in the same requirement group results from this reduced strictness. Note that if all the six indicators has to exceed the threshold to be sustainable, then fewer farms will pass the requirement for sustainability. This is clearly illustrated by the 10 farms in Guba. Two farms are judged sustainable under the present procedure. Otherwise only one farm (farm no. 1) would pass.

The two approaches to measuring sustainability, i.e., location specific versus constant indicators across farms, is closely related to the principle of substitutability among indicators. The location specific approach does not allow for substitution but requires that all indicators are above their respective threshold level. This is so since the indicators selected for each particular situation are those that are likely to be lower than threshold. This is why soil loss is a good indicator for steeplands where soil erosion can be high, but is not so in the flat lands where erosion is low. In the constant indicator approach, however, a selected indicator is measured for all farms regardless of its likelihood or non-likelihood of violating the threshold. Thus this approach is less strict and more farms likely to pass the sustainability test.

Appendix 1: Summary of the commonly mentioned sustainability parameters.

INDICATORS FOR FARMERS SATISFACTION	MEASUREMENTS
Productivity	
Net return to land	Economic outputs, economic inputs, farm-gate prices (inc. imputed prices), using direct measurement, periodic interviews, market surveys
Net return to labor	
Total factor productivity	
Yield	Kg/ha, Kg/person/year
Viability	
Cash flow; discounted cash flow	As above, over time (measured or projected; interest rates on farm credit (explicit or implicit); food surveys
Flow of net benefits; net present value	
Net farm income (after farm development)	
Flow of staple food availability	
Stability	
CV of productivity measures	Measurements of inputs and outputs, costs and returns, over time for each test farm; periodic number and kind of enterprises
CV of net benefits	
Diversity of enterprises	
Net returns in worst 20- of trials (minimum returns analysis)	measurements of key elements (e.g., yield, output price) across a sample of farms
Acceptability	
Labour	Person days per year
Membership of community organizations	number of organizations, type of organizations
Adoption indices	Adoption surveys examining degrees of adoption, farmer opinion, and likely constraints (e.g., tenure status)
Farmer ratings	Opinion poll of farmers, e.g., at a field day.

INDICATORS FOR RESOURCE CONSERVATION	MEASUREMENT
Quantity of the resource	
Soil loss (gain)	amount of soil formed - amount of soil loss
Woody perennial population	area of woody perennials/total farm area
Soil nutrient budget	added nutrient Vs biomass removed
Turbidity index	Suspended solids in run-off water
Erodability index	Soil loss under controlled rainfall simulation
Ecological diversity	Shannon's index (the total number of species cultivated, collected or used on the farm)
Quality of resource	
Topography	Slope, slope length
Soil stability	Water dispersable clay
Nutrient cycling	Finn's Cycling Index (Proportion of the nutrients within the system which are recycled within the system)
Bio-resource recycling	The total number of farm generated biological material flow within the farming system.
C:N ratio	Organic Carbon: Mineralisable Nitrogen ratio over time
Soil compaction	Soil resistance to penetration over time
Calico index	Degradation in tensile strength of a calibrated strip of buried calico over time. Surrogate measure of soil biological activity.
Ground cover	Averaged percent of soil surface covered by living or dead mulch during wet weeks (>50 mm rainfall per week)
Water stress	Crop rotation stress days per year